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IS 3599 (1966): Methods of measurement of cooling medium
temperature for electrical apparatus [ETD 1: Basic
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"Knowledge is such a treasure which cannot be stolen"

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Indian Standard

METHOD OF MEASUREMENT OF COOLING MEDIUM TEMPERATURE FOR ELECTRICAL APPARATUS

(Second Reprint SEPTEMBER 1984)

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Indian Standard

METHOD OF MEASUREMENT OF COOLING MEDIUM TEMPERATURE FOR ELECTRICAL APPARATUS

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METHOD OF MEASUREMENT OF COOLING MEDIUM TEMPERATURE FOR ELECTRICAL APPARATUS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 15 May 1966, after the draft finalized by the Electrotechnical Standards Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Determination of cooling medium temperature and ambient temperature is necessary to enable a user to select the most suitable apparatus to operate in unusual locations, such as in enclosed spaces, vicinity of equipment emitting heat.

0.3 In this standard a distinction has been made between ‘ ambient temperature ’ and ‘ cooling medium temperature ’ (*see* **2.1** and **2.2**).

0.4 In Indian Standards which deal with electrical apparatus*, thermal performance is generally specified by stating temperature-rise over a reference cooling medium temperature. The ambient temperature may or may not be a factor in determining the permissible loading of a piece of apparatus in service, depending on whether the apparatus is cooled by the medium immediately surrounding it, or by a cooling medium drawn from elsewhere. Unless specified to the contrary in the standard, the cooling medium for apparatus manufactured for use without an enclosure is usually taken as that immediately surrounding the apparatus, while for apparatus manufactured for use with an enclosure, the cooling medium is usually taken as that immediately surrounding the enclosure.

0.5 In preparing this standard, assistance has been derived from B.S. 2725 : 1956 ‘ Memorandum on the measurement of cooling-medium temperature when testing electrical machines, transformers and other electrical apparatus ’ issued by the British Standards Institution.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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*Apparatus is taken to mean any complete item to which specified limits of temperature-rise apply.
†Rules for rounding off numerical values (*revised*).

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1. SCOPE

1.1 This standard covers the essential requirements, construction of instruments and methods of measurement of cooling medium temperature.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Ambient Temperature — The temperature of the medium surrounding a piece of apparatus. It may differ at various distances and directions from the apparatus, and may be subjected to fluctuations.

> NOTE — Ambient temperatures are usually stated as substantially instantaneous values as measured by instruments having a negligible time constant.

2.2 Cooling Medium Temperature — The effective temperature (*see* 3) of the ambient air or other cooling medium above which the temperature-rise of the apparatus is measured.

> NOTE 1 — The cooling medium temperature, for forced-cooled apparatus, is the mean temperature of the ingoing cooling medium averaged over a time dependent on the rate of response of the apparatus under examination.

> NOTE 2 — The cooling medium temperature, for apparatus cooled by natural convection and radiation, is the mean value of the ambient temperatures, measured at a number of positions necessary to obtain a good approximation to the mean value, each element of which is averaged over a time dependent on the rate of response of the apparatus under examination.

2.3 Lagged Thermometer — An instrument for the measurement of cooling medium temperature which, by virtue of its thermal time constant, will average, with respect to time, the instantaneous values of temperature to which it is exposed.

2.4 Thermal Time Constant — The time which would be required for a given piece of apparatus to reach a temperature-rise equal to that attainable under steady-state conditions in a cooling medium at constant temperature, under specified loading conditions, if the initial rate of temperature-rise (when no heat was being dissipated) were maintained.

> NOTE — Fluctuations in the temperature of the cooling medium do not immediately produce a corresponding change in temperature of the apparatus being cooled due to the thermal time constant of the apparatus.

3. INSTRUMENTS REQUIRED FOR COOLING MEDIUM TEMPERATURE MEASUREMENT

3.0 General — A suitably lagged thermometer, starting at thermal equilibrium, will measure effective temperature at any instant. It is recommended to use such instruments for the measurement of cooling medium

temperature. Where a lagged thermometer (or its substitute) is used, it should be exposed to the same thermal conditions as the apparatus to be tested, for a period which is sufficient to permit them both to attain substantially the same temperature before any load is applied to the apparatus. In case of tests to determine ultimate steady temperature-rise, however, it is sufficient if the device is placed adjacent to the apparatus at the start of the heat run.

3.1 Instrument for Laboratory Use — For laboratory use where great accuracy is required, an adjustable instrument as described in Appendix A is suitable.

3.2 Instrument for Routine Testing

3.2.1 For commercial testing, one of the simple instruments described in Appendix B is recommended as being sufficiently accurate for practical purposes. An exact knowledge of the thermal time constant of the apparatus being tested is not essential because the error is already reduced to practical values by the use of a lagged instrument, and typical values of thermal time constants are sufficient for commercial testing. For example, the error that would occur if the temperature of the cooling medium were suddenly changed by 5 deg and maintained at the new temperature, is given in Table 1.

TABLE 1 MEASUREMENT ERRORS CAUSED BY SUDDEN CHANGES IN THE TEMPERATURE OF COOLING MEDIUM

TIME SINCE SUDDEN CHANGE IN THE TEMPERATURE OF THE COOLING MEDIUM, EXPRESSED AS A PERCENTAGE OF THE THERMAL TIME CONSTANT OF THE APPARATUS	ERROR IN DEGREES CELSIUS FOR AN INCREASE OF 5 deg C IN THE TEMPERATURE OF THE COOLING MEDIUM FOR RATIO OF THERMAL TIME CONSTANT OF INSTRUMENT AND THERMAL TIME CONSTANT OF APPARATUS			
	Negligible	0·5	1	2·0
(1)	(2)	(3)	(4)	(5)
10	+4·52	+0·43	0	—0·25
33	+3·58	+1·01	0	—0·65
67	+2·56	+1·25	0	—1·01
100	+1·84	+1·16	0	—1·19
133	+1·32	+0·97	0	—1·25
167	+0·94	+0·76	0	—1·23
200	+0·67	+0·58	0	—1·16

3.2.2 Column 2 of Table 1 shows that a considerable error may result from the use of a thermometer which has a negligible time lag (mercury thermometer or thermocouple) when measuring the temperature of a cooling medium. This is because the thermometer measures the changes

in temperature immediately, whereas the apparatus will respond slowly. The maximum error approaches 5 deg when measurement is made immediately after a sudden change of 5 deg in temperature of the cooling medium.

3.2.3 Columns 3, 4 and 5 of Table 1 show that by using lagged thermometers, which have between one half and twice the thermal time constant of the apparatus, the maximum error is reduced to 25 percent or less of the change in temperature of the cooling medium and that, accordingly, no great accuracy as regards matching time constants in commercial testing is necessary unless the temperature-rises to be measured are very small, for example, when dealing with power capacitors.

3.3 Use of a Similar Unloaded Piece of Apparatus — Where a similar unloaded piece of apparatus has substantially the same thermal time constant as that of the loaded piece of apparatus under examination, its temperature may be used as the cooling medium temperature as an alternative to that indicated by a lagged thermometer.

NOTE — In cases where the apparatus is cooled by natural circulation of oil or other medium, the time constant under unloaded conditions may be many times greater than that of its loaded counterpart.

3.4 Use of Instruments Giving Substantially Instantaneous Temperature Indication — Where an instrument which gives substantially instantaneous indication of temperature is used instead of a lagged thermometer, sufficient readings should be taken at appropriate time intervals and averaged over a time dependent upon the thermal time constant of the apparatus under examination.

4. POSITION OF MEASURING INSTRUMENT RELATIVE TO THE APPARATUS

4.1 The instruments are required to give measurements of the effective temperatures of the cooling medium supplied to the apparatus or drawn to the apparatus by natural convection, and from these the cooling medium temperature may be derived. Lagged thermometers will take care of time variations directly, but thermometers of negligible time constant will give readings that require to be averaged for variations with time to obtain the effective values.

4.2 In cases where the temperature of the cooling medium is uniform over the inlet area to the apparatus, for example, water cooling or uniform air blast, one instrument in the inlet pipe will suffice. One lagged thermometer will give the cooling medium temperature directly.

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.3 Where the temperature of the cooling medium is not uniform over the inlet area, and one instrument suitably placed in the inlet port will not measure the mean temperature, two or more instruments are necessary and the mean value of the effective temperatures so obtained is the cooling medium temperature. The mean value is the arithmetic mean of the lagged thermometer readings if the cooling medium has non-uniform temperature distribution but is entering at the same rate at all points of measurement. Where the flow is also not uniform, this should be taken into account in obtaining the mean value.

4.4 The number and location of instruments should be such that a good approximation to the mean value may be obtained. This aspect is generally specified in the relevant apparatus specification.

APPENDIX A

(*Clause* 3.1)

INSTRUMENT FOR THE MEASUREMENT OF COOLING MEDIUM TEMPERATURES SUITABLE FOR LABORATORY USE (INSTRUMENT WITH VARIABLE TIME CONSTANT)

A-1. CONSTRUCTION AND OPERATION

A-1.1 The design of the instrument is based on the use of a vacuum flask (*see* Fig. 1 and Fig. 2). A vacuum flask A is almost filled with transformer oil, and closed with a suitable plug B. Passing through the plug and reaching the bottom of the flask is a copper rod C, the top end of it being flush with the top surface of the plug. Below the oil surface, a helix of copper strip D is attached to the rod C at each turn; this improves thermal contact and minimizes temperature differences between various parts of the oil. The oil temperature is measured by the thermometer E passing through the plug. The copper rod C is drilled axially and a thinner rod F is a sliding fit in this hole, since it is essential that this rod F is gripped firmly over an appreciable length at all times, the hole in rod C is enlarged except for the top 25 mm or so and the rod C split as shown to provide a spring action. To ensure that no movement occurs when rod F is slid in and out, a rod C is made a tight fit in the plug, and is turned with a somewhat rough finish (or it may be lightly knurled). A 'convector' G, consisting of a number of thin copper fins attached to a central copper boss, is fitted to the upper end of rod F to exchange heat with the air. To minimize heat transfer by radiation, the convector is nickel- or chromium-plated to prevent tarnishing, and is highly polished.

7
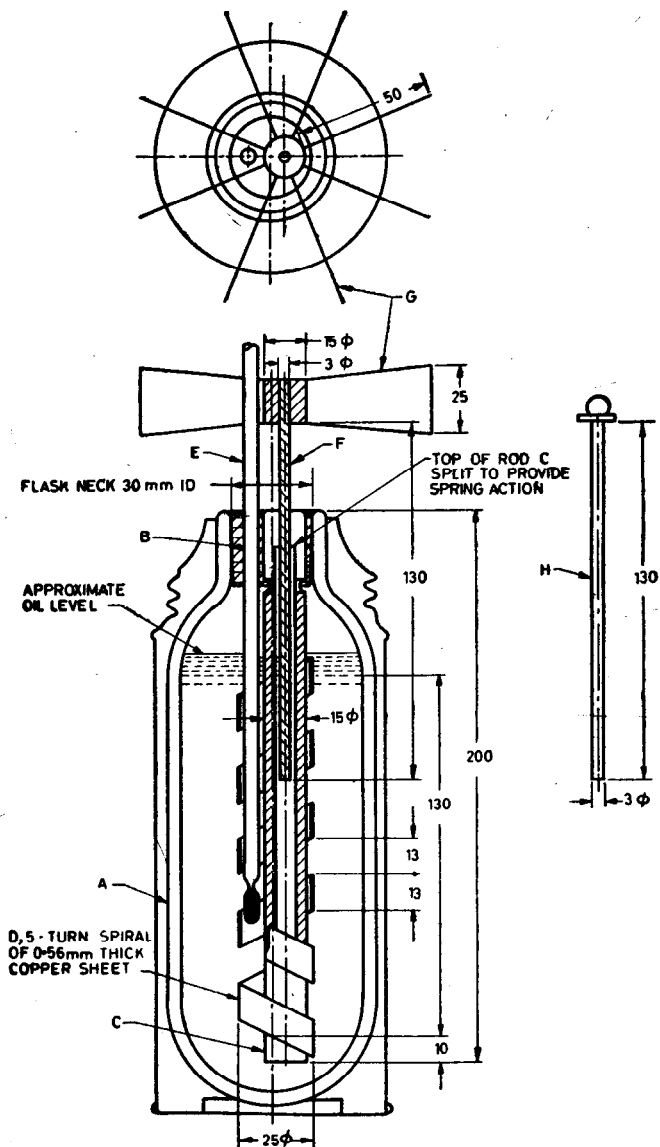
NOTE — A few leading dimensions are given for guidance.

All dimensions in millimetres.

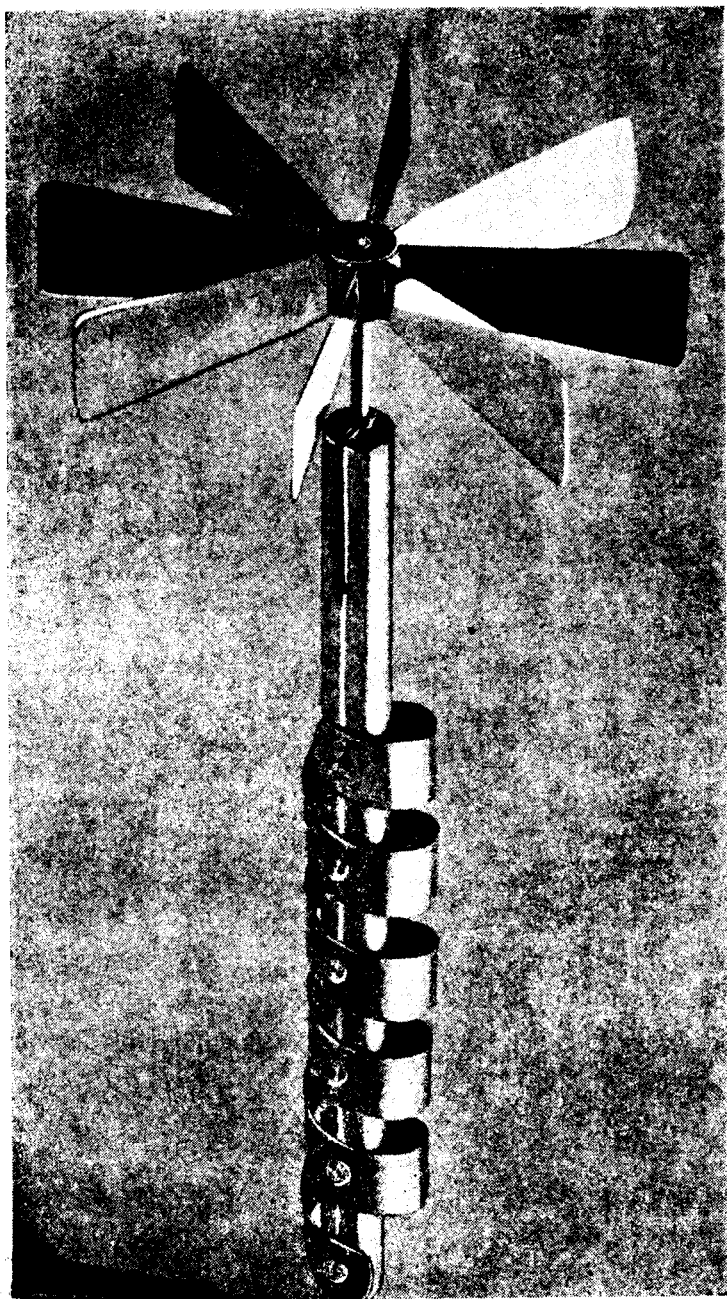FIG. 1   INSTRUMENT WITH VARIABLE TIME CONSTANT

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Fig. 2   Central Element of Instrument Shown in Fig. 1

A-1.2 The rod carrying the convector is slid up or down in rod C to alter the time constant of the instrument. The minimum time constant (maximum rate of heat exchange) is obtained with the convector lowered on to the top of rod C, so that there is minimum thermal resistance between the convector and the oil. As the convector is raised, so additional thermal resistance is introduced by rod F, and the time constant rises. However, heat is transferred to or from the surface of this rod, at a rate determined by the surface area exposed and the thermal resistance of the rod material, so that a limiting value is reached for the time constant in turn depending on the diameter and material of rod F (*see* Fig. 3, lower curve). To obtain higher values of time constant, another rod is used as shown at H in Fig. 1. This is similar to rod F, but has a small ebonite knob at the end in place of the convector; this serves merely to prevent the rod being accidentally pressed too far into rod C. Withdrawal of this rod increases the dissipating surface and decreases the time constant, which in this case tends to a minimum value equal to the previous maximum, as indicated in the upper curve of Fig. 3.
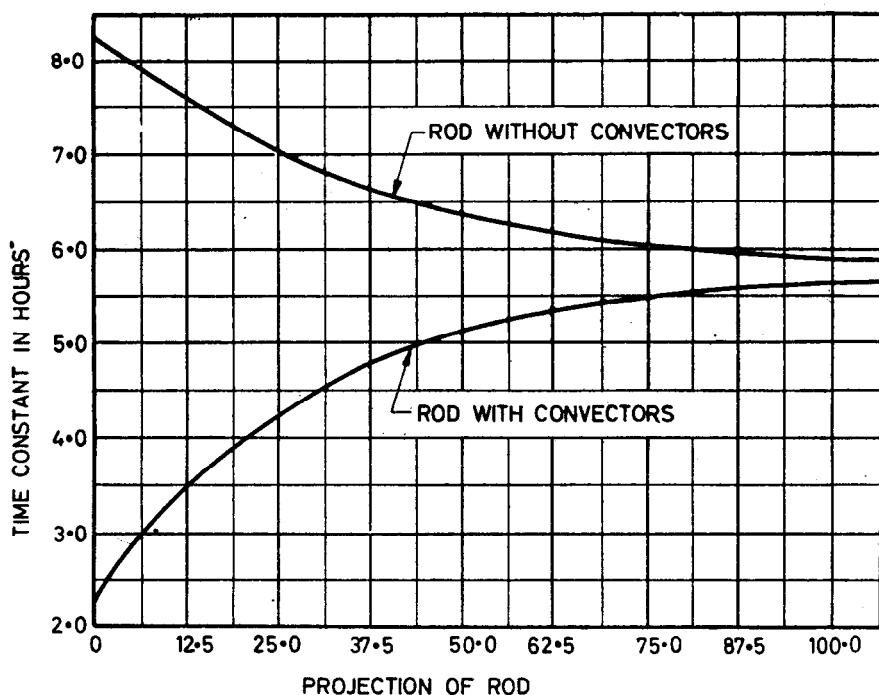

FIG. 3 CURVES PERTAINING TO THE CALIBRATION OF THE INSTRUMENT SHOWN IN FIG. 1

A-1.3 The dimensions shown in Fig. 1 and the calibration curves of Fig. 3 refer to a 0·6-litre vacuum flask containing 0·3 litre of low viscosity oil as specified in IS : 335-1963*. Rod *C* is made of copper and is of 13 mm in diameter and the 25 mm diameter five-turn helix is also made of copper, 0·56 mm in thickness and 13 mm wide. To obtain a robust construction with a conveniently large vertical movement of rods *F* and *H*, these rods are made of brass of 3·15 mm diameter, and are at least 130 mm long. The convector has eight fins of 0·56 mm thick sheet copper, each fin being approximately 50×25 mm; the design of this component is not critical but the surface area should not be much smaller than given by these dimensions. The thermometer is conveniently a 350-mm mercury-in-glass pattern, covering the range —5°C to +50°C and subdivided in tenths of a degree Celsius.

A-1.4 As shown in Fig. 3, the instrument covers a range of time constants from 2¼ to 8¼ hours approximately. Larger or smaller sizes of flask may be used to give other ranges, for example, 1·14-litre flask using the same component sizes except for a longer central rod and helix, and containing 0·7 litre of oil, gives a range from 4¼ to 13 hours.

A-1.5 Any instrument made on the lines indicated should be calibrated before use.

A P P E N D I X   B
(*Clause* 3.2.1)

INSTRUMENT FOR THE MEASUREMENT OF COOLING MEDIUM TEMPERATURES, SUITABLE FOR USE MAKING COMMERCIAL TEST (INSTRUMENT WITH FIXED TIME CONSTANT)

B-1. CONSTRUCTION AND OPERATION

B-1.1 In Fig. 4, details are given of the design of a fixed time constant thermometer. It consists of a cylindrical mild steel block, 75 mm in diameter and 140 mm high, mounted on a wooden base. It is surrounded by a suitably plated shield, 120 mm diameter, which serves to increase the time constant of the block without adding appreciably to the weight, and also gives an easily reproducible permanent surface to reflect radiation. A hole, 12·5 mm in diameter, is drilled axially into the block, and contains a little transformer oil for thermal contact; a thermometer is suspended from a cork and dips into the oil as shown. For convenience, carrying handles may be attached to the block itself to avoid handling the surface of the shield.

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*Specification for insulating oil for transformers and switchgear (*revised*).
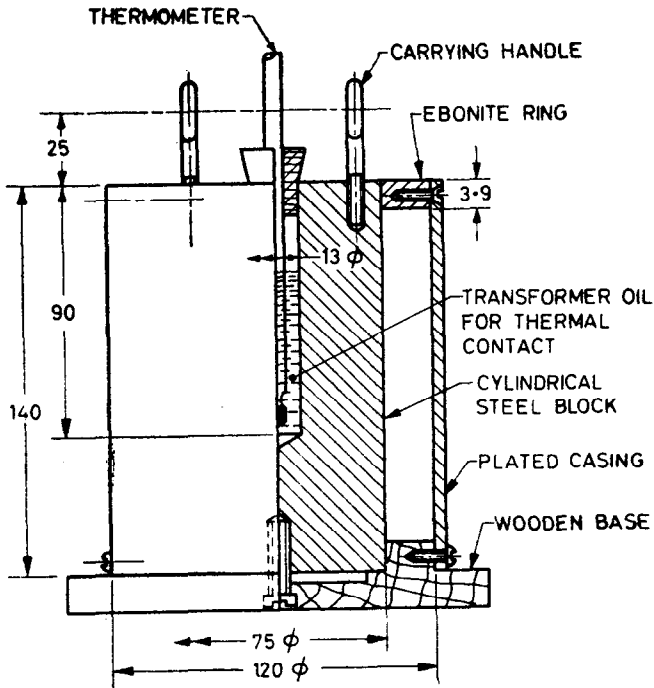
All dimensions in millimetres.

FIG. 4   INSTRUMENT WITH FIXED TIME CONSTANT

B-1.2 With the sizes given the thermometer has a time constant of almost exactly 3 hours, and the design is such that it may be made to the drawing and used without calibration. The time constant may be increased to about 5 hours by filling the annular space between block and screen with cotton wool; removal of the screen reduces the time constant to about 2 hours. Small changes in dimensions will not appreciably affect the time constants given.

B-1.3 A 0·6-litre metal can, painted outside and containing low viscosity oil will serve as a suitable thermometer container. With such an arrangement the time constant may be varied between about 20 and 80 minutes, depending on the level of the liquid. The can should be of light gauge metal and have a diameter slightly less than its height in order to obtain the time constants referred to above. If water is used in place of oil, slightly longer time constants are obtained, but precautions should be taken to prevent evaporation if the ambient temperature is high and the humidity is low.

B-1.4 A 0·3-litre size cylindrical glass bottle, containing about 0·2 litre of low viscosity oil may also be used. This will have a time constant of approximately 50 to 60 minutes at normal room temperatures.

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INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

QUANTITY	UNIT	SYMBOL
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

QUANTITY	UNIT	SYMBOL
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

QUANTITY	UNIT	SYMBOL	DEFINITION
Force	newton	N	$1\ N = 1\ kg.m/s^2$
Energy	joule	J	$1\ J = 1\ N.m$
Power	watt	W	$1\ W = 1\ J/s$
Flux	weber	Wb	$1\ Wb = 1\ V.s$
Flux density	tesla	T	$1\ T = 1\ Wb/m^2$
Frequency	hertz	Hz	$1\ Hz = 1\ c/s\ (s^{-1})$
Electric conductance	siemens	S	$1\ S = 1\ A/V$
Electromotive force	volt	V	$1\ V = 1\ W/A$
Pressure, stress	pascal	Pa	$1\ Pa = 1\ N/m^2$